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Multidisciplinary Design and Analysis for Commercial Aircraft

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**Multidisciplinary Design and Analysis for Commercial Aircraft**

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## **Abstract**

Multidisciplinary design and analysis (MDA) has become the normal mode of operation within most aerospace companies, but the impact of these changes have largely not been reflected at many universities. On an effort to determine if the emergence of multidisciplinary design concepts should influence engineering curricula, NASA has asked several universities (Virginia Tech, Georgia Tech, Clemson, BYU, and Cal Poly) to investigate the practicality of introducing MDA concepts within their undergraduate curricula. A multidisciplinary team of faculty, students, and industry partners evaluated the aeronautical engineering curriculum at Cal Poly. A variety of ways were found to introduce MDA themes into the curriculum without adding courses or units to the existing program. Both analytic and educational tools for multidisciplinary design of aircraft have been developed and implemented.

## **Introduction**

Industry wants graduates who are educated as aeronautical systems engineers, with an understanding of the following concepts: how an aircraft should be designed, how an aircraft should be built, and how the two relate to each other [1]. This project brings together two Cal Poly engineering departments—Aeronautical and Industrial & Manufacturing—to develop a systematic curricular approach to the integration of several non-traditional design-related subjects with the commercial aircraft design process. The objective includes creating a curriculum which leads to an overall improvement in design methodology which meets the needs of industry. To accomplish this, the faculty have teamed with industry and student partners to modify the curriculum for this improved educational delivery system. The project includes introducing students to various aspects of multidisciplinary design and analysis, including the concepts of: design for manufacturing; concurrent engineering; quality and reliability engineering; cost, economic, and market analysis; and legal, ethical, environmental and other social issues. There is also a focus on curriculum modifications to include regulatory laws, specific analytical tools for costing and designing an aircraft for reliability and manufacturability, and manufacturing-based design. Students have been introduced to solids modeling and manufacturing requirements early in the curriculum to improve their concurrent engineering abilities.

## **The Role of Multidisciplinary Analysis**

Successful development of a product requires integrated interaction between many groups. This integrated interaction must focus on developing a product with a high level of customer acceptance. The normal product development cycle in industry is shown as a continuous cycle (see Fig. 1). In this cycle the customer is also the ultimate product requirements definer. In addition, integrated product development must encompass all phases of the design, including project management, design engineering, systems integration, and production.

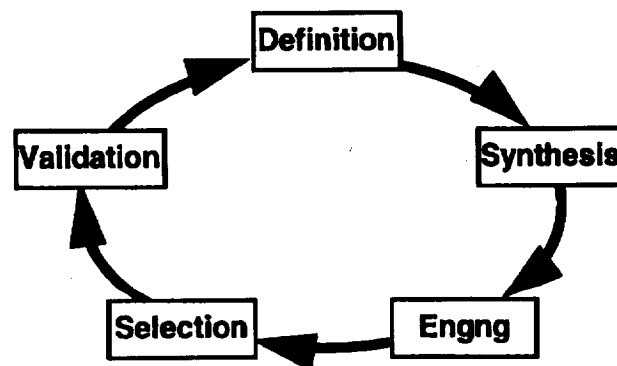


Figure 1. The Design Synthesis Process

In this process the design engineer creates and transforms ideas and concepts into a product definition. The role of the design engineer is the creation, synthesis, iteration, and presentation of product solutions that satisfy the needs of the customer—whether the customer is an airline, the public, or the manufacturer. This is a multidisciplinary role. In this role the design engineer works with all the program elements and with engineering specialists to synthesize their needs into a product definition. One model of the design synthesis process was shown in Fig. 1. The integrator interacts with all the program elements to develop the product definition, including defining the configuration, documentation, validation, support, and disposal. These multidisciplinary interactions and the resulting products are shown in Fig. 2.

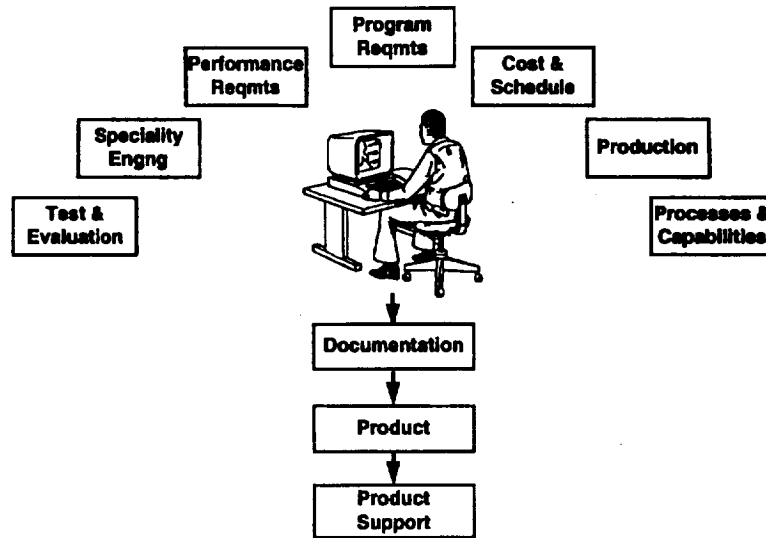


Figure 2. Multidisciplinary Design Interactions

Learning about the interactions in the aircraft design process under conditions that simulate an aerospace company multidisciplinary team approach is a very important element of the design sequence. Our students begin to learn the difficulties of team projects, the pressure of schedules and deliverables, and the intricacies of the aircraft design process, but there is much more for them to learn. The Boeing design/build team concept (or other team concepts) can be instituted, for example. By including an understanding of customer requirements as well as manufacturing requirements, the students will gain an even broader and deeper knowledge of the entire concurrent design process. At the completion of the sequence the student teams will have generated a viable aircraft product definition, but the real product will be young designers who have the ability to work effectively in a multidisciplinary team.

Cal Poly's approach to education is modeled after the words of Aristotle, who said over 2000 years ago: "What we have to learn to do, we learn by doing." We feel very strongly that introducing topics of interdisciplinary design and manufacturing to freshmen will enable them to appreciate better the concepts and tools they will be studying throughout the curriculum. Using contemporary design methodologies in a laboratory equipped with computer workstations, the student teams work on their projects for one academic year. Starting with the requirements they progress through design definition to a final report, project presentations to industry experts, and a scale model of their aircraft.

### **The Previous Design Program**

The design course in the Aeronautical Engineering Department has evolved over the past forty years from a course where students learned how to construct an airplane to courses where they perform detailed preliminary design of an aircraft, including many of its systems. This evolution has been greatly enhanced by Cal Poly's participation in the NASA/University Space Research Association Program (USRA), enabling the department to give the students a more intensive aircraft design experience by allowing them to work on real-world design problems. Many of the aircraft design problems were industry-generated, with industry engineers actively involved in the department's instructional program via an advisory board. The board is made up of approximately twenty engineers and engineering managers from a cross-section of the aerospace industry. They supply the support, both financial and technical, which makes our design course successful.

The previous undergraduate aircraft design curriculum at Cal Poly was a well-integrated, intensive, year-long course, requiring prerequisite knowledge in aerodynamics, flight performance, and aircraft structures as well as concurrent knowledge in gas dynamics, propulsion systems, and stability and control. The course included introductory information on aircraft sizing, aircraft operations, weight estimation, performance requirements, maneuvering, propulsion systems, environmental systems, and configuration layout. Issues which were marginally addressed in the course included environmental impact, economics, and airline requirements.

The design work was conducted in an inter-disciplinary fashion, with design groups working as teams throughout the three-quarter sequence. The course culminated in a design review at the end of the year. The industry design review teams include engineers with expertise in aeronautics, manufacturing, propulsion, maintenance, structures, and control systems. The engineers come from Boeing, Lockheed Martin, Northrop Grumman, Rolls Royce, General Electric, United Airlines, as well as NASA and others. Students gained valuable insight into the difficulties in designing an aircraft within the constraints of a group project with a deadline. Unfortunately, one of the areas where the students were deficient was in tying their designs into the manufacturing world. The previous course only marginally addressed issues such as design for assembly (DFA), design for manufacturing (DFM), economic analysis, design to cost and time constraints, and various other considerations. The students also were not prepared to work in teams, with the design course being their first in-depth team engineering experience.

### **The New Design Program**

In examining the literature, and taking a hard look at what we were doing in our curriculum, we found that the observations of Robert R. Furgason were very true:

*One continual comment, especially from employers, is that our engineering graduates are well prepared in the quantitative aspects of the scientific, mathematical, and engineering components of their education, but they often lack what we might term the 'soft' or 'people' skills; that is, the ability to communicate effectively – write, speak, and listen; the ability to work effectively in teams; an appreciation of the economic, environmental, safety, and social factors present in most settings that often dictate the approach that is used; and a realization of the political environment in which they work – both internal and external. In education, we stress the 'right answer' approach and our graduates do not have a good appreciation that most things we deal with are ambiguous and we seek best answers involving many subjective elements. Our curricula should be modified to incorporate these aspects into the educational process [2].*

The previous curriculum was examined with an eye toward how it addressed multidisciplinary topics. A group of faculty and students then brainstormed a list of factors, which affect multidisciplinary design within the curriculum, as well as other factors, which were not within the curriculum. These factors included: problem identification, the design process, the decision-making environment, process identification, and quality issues. A detailed investigation and

discussion about each of these issues resulted, with a great deal of information being generated about the gaps and problems within the curriculum. The areas that were identified included: synthesis vs. analysis, working in groups, “data” (information) and where to find it, willingness to fail and start over (the iterative process), and the student's desire to specialize. In addition, the group realized that there were a number of technical/educational areas where the students simply were not being prepared by the curriculum, including concurrent engineering concepts, design tools, group dynamics, total quality management (TQM), and a basic understanding of the competitive nature of the commercial aircraft industry.

After developing the concepts for improving the curriculum and developing analytic tools the program was presented to Phil Barkan of Stanford University, a well known expert on engineering product development. Finally, the program was presented to a group of industrial associates consisting of engineers from Boeing, Northrop Grumman, and NASA Ames Research Center. These engineers would serve as the points of contact for the project, providing input as to how industry is approaching MDA concepts. Inputs from all of these constituents were incorporated into the program.

Our industrial associates told us that the following areas were of major concern to their companies at the present time: integrated scheduling for manufacturing, computational modeling of manufacturing systems, understanding trade studies and process design, integrated product development, and the use of advanced tools for the design process. In addition, our industry partners said that engineers graduating from universities today are, in general, unprepared to consider an aircraft as a system or to see the design as requiring a collaborative effort. This collaboration is not limited to the traditional relationship between the aerodynamicist, structural engineer, propulsion engineers, and controls systems analyst, but must include being aware of the customer, manufacturing implications, cost analysis, and the time it takes to design and construct an aircraft.

All of these concerns can be summarized as a need to develop a systematic approach to the integration of manufacturing with the aircraft design process. We have addressed the solutions to these concerns by combining three traditionally separate elements: analysis of the market place and the needs of the customers, traditional design analysis, and the manufacturing process. The initial goal is to produce engineering students who are capable of functioning in a complex industry—students who will have the ability to affect the cost, quality, and cycle time of new aircraft products. This goal is realistic, especially considering the tradition of engineering at Cal Poly and our close ties with industry.

### **Multidisciplinary Design and Analysis Curriculum**

The over-riding restraint on any new approaches to engineering education from an MDA perspective was that the MDA material could not add any units to the existing curriculum. Most universities across the country are currently seeking ways to reduce the total number of units required for graduation, and our engineering curriculum was already at the maximum number of units allowed. In addition, the curriculum changes had to provide an integrated approach to MDA from the freshman year through the senior year, with modules taking place throughout the student's academic career. We believed that these restraints were inviolable.

There are three main areas within the curriculum which were modified to better prepare the students for tackling MDA themes:

- the freshman engineering curriculum,
- a sophomore introduction to design,
- teaching existing engineering analysis course from a multidisciplinary perspective.

Faculty activities have included a team-teaching approach to segments of the curriculum where these

issues are relevant. The goal is to integrate the multidisciplinary approach throughout the curriculum, from freshman engineering courses through master's-level design courses. This includes a new freshman engineering design course, a new CAD/CAM modeling course, a new sophomore design course, and a comprehensive approach to design in the senior design courses. Other collaborative efforts have been sought at strategic points in development of the curriculum to enable quality, cost and economics, and concurrent engineering concepts to be introduced.

The previous freshman-level engineering curriculum offered the students a number of courses, which were aimed at giving them skills and capabilities for working as engineers in industry. These courses included a drafting course, a manufacturing survey, and a hands-on course in manufacturing processes (such as casting, sheet metal, etc.). These courses required a total of 5 quarter units (out of a total curriculum of 210 units). The previous courses that introduced freshmen to design documentation and manufacturing were not integrated, and the CAD tools were PC-based. It had already been recognized that these courses should be updated and integrated, beginning with combining the drafting course and the manufacturing processes course.

A course for aeronautical engineering students has been introduced to address some of these concerns, which integrates basic knowledge of CAD with manufacturing topics, leading to a project where the students would be required to design, manufacture, and test a product. This course helps to motivate students and excite them about the curriculum, while giving them self-confidence and insights into some of the real problems, which are encountered in aircraft, design and manufacturing.

The integration of CAD/FAB and manufacturing at the freshman level was felt to be an important next step in the curriculum review process. An integrated foundation course was seen as an excellent means to introduce manufacturability, DFA/DFM, and concurrent engineering to the students in a single, unified setting. At the same time the change to an industrial solid model-based, integrated CAD/CAM tool was accomplished. Commercial engineering software was installed on workstations at the university and was used to teach a course in CAD/FAB. Experience in the pilot courses showed that solid modeling is easier to teach than wire-frame modeling because of the ease of developing multi-part assemblies, generation of computer-aided engineering (CAE) meshes, drawings, and CAM models. Students gain a greater degree of understanding through such an integrated course, which demonstrates the strong relationship of design decisions to manufacturability. Results of the work are available in [3] and [4].

The Industrial & Manufacturing Engineering Department has also developed and implemented three Product-Process Design course for graduate students and seniors within the new Manufacturing Engineering B.S. program. These courses present concurrent engineering concepts, Quality Function Deployment (QFD) [5], and Design for Manufacturing, Assembly, Maintainability (DFX) for integrated product engineering [6]. The experience gained in teaching these courses has helped the faculty make important strides in formulating and improving the freshman class for Aeronautical Engineering students.

Changes have also been made in the freshman course taught in the Aeronautical Engineering Department. This course gives students basic information about airfoils, wings, airplanes, and performance, as well as information about the aerospace industry. The students formerly completed this course by participating in a group balsa wood glider design [7]. The course has been modified to include a variety of team design projects, including a team rocket design, which culminates in a test firing. Students are also introduced to a variety of fundamental MDA concepts, such as the importance of cost and manufacturability to the design process.

The sophomore level computing course has been modified to include CAD/FAB, cost analysis, and integrated product development. These themes are being introduced within the context of a team aircraft design problem; the students create a CAD model of an aircraft, evaluate the aerodynamics and performance characteristics, and conclude by reporting on their results. This builds on the student's earlier design experience and extends it to a higher level.

Finally, existing junior-level courses have been evaluated for inclusion of multidisciplinary topics, especially for development of the student's understanding of manufacturing and the importance of group projects and teamwork. Team design projects have been added in the junior year in aerodynamics and guidance & control courses, some of which can be also be merged with existing faculty research and collaboration with industry.

As more “real world” problems are introduced into the curriculum in technical areas such as aerodynamics, controls, structures, and propulsion, the students will see why it is important to think across disciplines, rather than to “compartmentalize” their learning. The end result will be that students are better prepared to conduct multidisciplinary design when they reach the Flight Vehicle Design course in the senior year.

### **Analytic Tool Development**

A variety of technical areas are lacking within our current curriculum that we believe are necessary to prepare our students to be able to do a better job designing aircraft. These needs fall into a number of categories: aircraft design tools, trade study software, integrated scheduling systems, integrated product development, and various engineering design and analysis tools. In fact, we were overwhelmed when we looked at the list of technical background requirements for students as they enter an aircraft design course. The problem becomes how to effectively introduce students to a larger body of knowledge without just “throwing” more courses at them. All of this must be done while simultaneously considering that most people believe engineering curricula are already overburdened.

The basic approach is to work on discovering more efficient ways to deliver knowledge to the students, while ensuring that these technical areas are well covered and thoroughly understood. We have developed computer-based teaching tools which will introduce students to complex topics such as aircraft handling qualities, a topic which is usually beyond the scope of the undergraduate curriculum, but which is a basic requirement for performing a preliminary design. While working with our industrial associates we also determined what is valuable in performing multidisciplinary optimization (robustness, reliability, etc.), systems engineering, and linking various analysis areas. The large quantity of information required for performing multidisciplinary design will have to be shaped into essential analytic areas—each of these areas will have extensive analytic tool development performed by the graduate students. Examples of some of the engineering design tools, which have been, developed follows.

Inter-disciplinary optimization The project supported several students to work on developing analytic tools that can take an aircraft geometry, model the aerodynamics, develop a set of stability derivatives, develop control systems, and “fly” them on a simulator. Programs such as CONDUIT were developed to attain these goals, and are described on our World Wide Web page (<http://daniel.aero.calpoly.edu/~amdaf/amdaf.html>). Several references for these projects are listed in the appendices.

Designing to meet cost, cost estimating, and learning curves It is essential for students, as well as industry, to understand cost drivers—that is, which design decisions lead to costly manufacturing processes? Simple design rules and concepts could be identified and introduced to the students. Although current Industrial & Manufacturing Engineering courses address these areas, we have not provided adequate preparation to Aeronautical Engineering students in this topic. The project objective was to explore the means by which we can convey these skills to students at an early stage so that they will be able to apply the concepts in their senior design sequence. The project developed a portable learning module that enables students to estimate manufacturing costs, including learning curve estimates. This program is available on request.

Integrated Product/Process Development (IPPD) One of the areas which engineering students seem lacking is in their ability to develop and design seeing the “larger picture”. A variety of tutorials have been developed which introduce the students to the concepts of IPPD and allow them to realize the impact of this concept on the design process. The tutorials have been implemented on the World Wide Web (<http://daniel.aero.calpoly.edu/~amdaf/amdaf.html>). A small team of graduate fellows carried out research and development activities leading to the development of a multi-module web-based tutorial on “Integrated Product Development of Commercial Aircraft”. This web-based tutorial has attracted considerable interest worldwide with numerous follow-up calls from

engineers and scientists from around the world, who located this web site from their search engines and needed additional help.

Business Aspects, Integration, and Market Analysis These topics are addressed within the Industrial & Manufacturing and Business curricula. In this project we started by assessing the level of need and required level of proficiency for Aeronautical Engineering students. Based on that assessment we attempted to understand how industry functions—how is design done currently? Students visited engineering sites as research analysts gathering data with particular focus on merger/acquisitions and relative effects for either design or development activities. Some of this information has been displayed in our web page. Some structured analysis tools currently in use within Industrial & Manufacturing Engineering classes were re-structured for application within the context of aeronautical systems design and implementation.

Approach to team building Teambuilding is a crucial component of the research and development process. Concurrent engineering has been found to require an increased emphasis on team building, especially because of problems created by the more inter-disciplinary nature of concurrent engineering teams [6]. It is for this reason, along with our observations of students in their design course and the input we have received from industry, that we believe team building to be a crucial area for the success of multidisciplinary design.

The primary obstacle at the university seems to be the current curriculum style, which promotes independence over teamwork. Students are put through several years of engineering science courses as individuals, where group work is discouraged and even penalized. The problem with this approach has been noted by engineering educators at many universities, and has led to curriculum modifications, which introduce group projects in the freshman [7], sophomore [8], and senior years [9]. We believe that for the senior design experience to be truly valuable from a team viewpoint, the students must be given team skills earlier in the curriculum and throughout the curriculum.

Team skills of our current students have been observed and tutorials and team-building exercises have been developed. These tools are also being introduced to students in the lower division courses so that their team skills will be well developed by the time they reach the senior design class. A variety of these topics are discussed in greater detail in [10] to [13]. The tutorials have been included in Appendix E.

### **Student Participation**

An announcement was circulated among students at Cal Poly for participation in the project (see Appendix C). Approximately twenty students responded to the announcement and several rounds of interviewing and discussion followed until students were placed on projects that made the best use of their background and experience. The students were hired and the research projects began serious work at the beginning of the Winter Quarter 1995.

The under-represented status of the students who are participating at both the graduate and undergraduate levels are shown below. As was stated in our proposal, every effort was made to include women and minorities on these projects. The percentage of students listed below is the number of students from the under-represented group divided by the total number of students working on the project (whether those students are full or half time). Cal Poly does not consider Asian students as being from an under-represented group, although we had a number of Asian students on the project. Double counting takes place in some cases (e.g. women minorities). It should be noted that the percentages closely match the overall percentages of students in engineering at Cal Poly.



<u>Group</u>	<u>Number of Students</u>	<u>Percentage</u>
Women	4	17%
Ethnic Minorities	5	21%

<b>Name</b>	<b>Ethnic Minority (under-represented)</b>	<b>Female</b>	<b>Current Location (if known)</b>
Jaime Alvarez	X		Lockheed-Martin & MS student at Stanford
Fritz Anderson			Systems Technology, Inc.
David Baker			NASA Ames (contractor)
Michael Brockway			Lockheed-Martin
Greg Brown	X		
Leticia Bustamante	X	X	
Maria Cacapit	X	X	Parsons Management
Daniel Chen			IBM
Joe Fournell			Intel
Chad Frost			NASA Ames
Michael Graham			Hitachi
Gene Hansen	X		J.D. student at Santa Clara Univ.
Doug Hiranaka			NASA Ames (contractor)
Michael Keidel			Northrop Grumman
Mark Kettering			PhD student at Virginia Tech
Eric Koliander			Sharp Electronics
James Menon			MS/MBA student at Cal Poly
Mark Morel			Boeing
Larwrence Rinzel			M.S. student at Cal Poly
Dani Soban		X	PhD student at Georgia Tech
Joel Sullivan			Loral
Greg Thompson			Ernst & Young
Deanne Trigs		X	TRW
Tim Weise			Hughes Space & Communications

## **Conclusions**

The changes required in order to introduce MDA topics to undergraduate students are large and complex. Existing engineering curriculums are over-burdened and new concepts cannot be introduced by simply adding more courses. A multidisciplinary team approach to solving this problem has resulted in a curriculum modification and analytic tool development program that is well under way at Cal Poly [14]. New approaches to MDA have been added to the curriculum beginning with the freshman year, with planned changes to take place soon in the sophomore and junior years. The Aeronautical Engineering faculty have been very supportive of these changes to the curriculum.

Specific changes to the curriculum include:

- the development of a freshman CAD/FAB course
- modifications of the freshman orientation course to include team design projects
- planned changes to the sophomore programming course to include CAD/FAB, cost estimating, IPPD, and team work
- various team design projects in the junior year
- new understanding and improvements for the senior design class as a result of the previous curriculum improvements

These alterations to the curriculum and analytic tool additions have and will make great improvements in the education of Aeronautical Engineering students at Cal Poly.

## **Acknowledgments**

This work was sponsored by NASA Training Grant NGT-10012, supervised by Gerry Seidel of NASA Headquarters and Paul Gelhausen of NASA Ames Research Center. We also want to thank the late Phil Barkan of Stanford University for his wonderful help in the initial stages of the project. In addition, the engineers of the following organizations have been very important to our work: Boeing, Northrop Grumman, and NASA Ames Research Center.

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## **Appendix A—Conceptual Framework**

### **Possible Topics For Multidisciplinary Design**

- 1) Environmental aspects (both manufacturing and product)
- 2) Design for environment (including disposal cost)
- 3) Design for manufacturability
- 4) Design for global competitiveness (Airbus, Taiwan, China, Japan)
- 5) Marketing
- 6) FAA Regulations
- 7) Industrial/International consortia
- 8) Case studies (portability)
- 9) CAD/CAM and CAD/FAB
- 10) Design process/teamwork/types of teams
- 11) Industry involvement (both directions)
- 12) Process identification/ownership
- 13) Interaction with manufacturing/shop
- 14) Quality
- 15) Communications with team
- 16) Rewards (industry and academia)
- 17) Curriculum
- 18) How does this work in academia (faculty, students, etc.)?
- 19) "Relate"tivity
- 20) Upside-down curriculum
- 21) Systems engineering
- 22) Projects/problem solving
- 23) Analysis/synthesis
- 24) Problem posing
- 25) Creativity vs. analysis
- 26) Interaction with Stanford?
- 27) Best practices ("war room" or computer)
- 28) Decision making
- 29) Risk taking
- 30) Legal environment
- 31) Social issues
- 32) Ethics
- 33) Research Skills/experiment design
- 34) Design information/data
- 35) weights/costs/sizes

- Problems in Design:
  - Synthesis vs. analysis
  - Working in groups
  - "Data" and where to find it
  - Willingness to fail and start over (the iterative process)
  - Student's desire to specialize:
    - aero/fluid dynamics
    - propulsion
    - structures
    - controls
    - design/configurators
    - "ilities" (maintainability, reliability, etc.)
    - chief designer
  - Tools (computers, CAD, etc.)
- Influences on Current Course:
  - Previous instruction
  - Textbooks
  - Industry input
- Groups
  - What are the characteristics of groups?
  - How do they function?
  - Everyone won't learn everything
  - There is no answer
- Where can we attack these problems?
  - Organization is more important than technical side
  - Student's perspective:
    - team building away from academic environment
    - break down barriers for communication
    - Advanced Human Factors course:
      - first two weeks were team building
      - grade was peer-dependent
      - presentation made to department

- would help if it happened earlier in curriculum
- Freshman sequence
  - team building/projects
  - CR/NC?
- teamwork grading
- create a different environment
- leads to knowing abilities and skills
- Learning TQM
  - Who are my customers?
  - What am I delivering?
  - What is the process?
- Data
  - subscribe to periodicals
  - learn how to access information (library, data bases)
  - incorporate into Freshman sequence
  - "coziness" is a problem--maybe they need to be told what to do with orientation and an assignment
  - repeat throughout the curriculum
  - could GE&B help in this area?
  - there is little or no expectation to do research in engineering courses
  - require students to have a campus computer account
  - they don't retain CAD skills
  - "state of the art" is always changing
  - should know word processing, spread sheets, etc.

## **Appendix B—Advisory Board Participation**

<u>Name</u>	<u>Company</u>
Bob Wulf	Northrop
Willis Hawkins	Lockheed
Hal Wochholz	McDonnell Douglas Helicopters
Beth Anderson	Douglas Aircraft
Tom Galloway	NASA Ames Research Center
Phil Barkan	Stanford University

# **M.S. Graduate Students Wanted**

in

**Aeronautical Engineering  
Industrial/Manufacturing Engineering  
Engineering Management**

for NASA fellowships to work on research projects dealing with

# **Multidisciplinary Design and Analysis for Commercial Aircraft**

Research will be conducted on the following  
aeronautics-related topics:

Controls Design and Analysis  
Handling Qualities  
Structures  
Propulsion Systems  
Applied Aerodynamics  
Teambuilding  
Integrated Product Development  
Rapid Prototyping  
CAD/CAM/CAE Applications  
Economic Analysis

Fellowships will be for one year and include a salary and tuition.  
The fellowships may be renewed.

**Women and minorities are strongly encouraged to apply**



## Appendix D—Publications

- [1] S. Alptekin and J. Ervin, "Fuzzy logic control of a model airplane," Proceedings of IEEE International Conference on Systems, Man, and Cybernetics, Oct. 1998.
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## **Appendix E—Team Work Manual**